ELECTRONICS AND SEMICONDUCTORS

OVERALL COURSE OBJECTIVES:

The courses intend to cultivate an extensive understanding of Semiconductor and Digital Signal Processing principles. This includes a comprehensive knowledge of core concepts such as the quantum theory of solids, device functionality, modeling and simulation, semiconductor packaging and characterization, and their practical application within various electronic advancements. Aimed at fostering both theory and practical skills, students will gain a strong foundation in these crucial areas of modern electronics and computer science technology.

LEARNING OUTCOMES: On successful completion of the course the students shall be able to:

1. Recognize and apply the principles of Digital Signal Processing (DSP) including Fourier analysis, filter design, sampling, interpolation, and quantization while bridging the gap between theoretical understanding and practical analysis.
2. Discover, analyze, and discuss the quantum theory of solids and carrier behaviors in semiconductors, including the analysis of energy band structures, carrier statistics dynamics & their impact on conductive properties.
3. Interpret and evaluate the functionality of Transistors, pn Junctions, Metal Semiconductor contacts, and Diodes, comprehending their equilibrium and biased conditions, capacitance characteristics, or breakdown behaviors.
4. Compose and construct SPICE models for high-voltage Schottky and p-n diodes, mastering the understanding of their physics and crystalline semiconductors fundamental to their analysis.
5. Understand the foundational semiconductor materials and devices, and their importance in CMOS manufacturing, applying the concepts more broadly.
6. Apprehend and highlight the importance of semiconductor packaging in current electronics, understanding its anatomy, function, various types, their materials, design, and reliability.

	Digital Signal Processing 1: Basic Concepts and Algorithms
Digital Signal Processing - I	Digital Signal Processing 2: Filtering
	Digital Signal Processing 3: Analog vs Digital
Digital Signal Processing - II	Digital Signal Processing 4: Applications
	Semiconductor Physics
	Diode - pn Junction and Metal Semiconductor Contact
Semiconductor Devices - I	Transistor - Field Effect Transistor and Bipolar Junction Transistor
	High Voltage Schottky and p-n Diodes
	Introduction to Power Semiconductor Switches
Semiconductor Devices - II	Fundamentals of Semiconductor Characterization
	Introduction to Semiconductor Packaging
	Semiconductor Packaging Manufacturing
	Advanced Semiconductor Packaging
	Electrical Characterization: Diodes
	Electrical Characterization: MOSFETs
	Electron and Ion Beam Characterization
Semiconductor Characterization & Packaging	Optical and X-Ray Characterization

COURSE CONTENT:

Module 1: Digital Signal Processing 1: Basic Concepts and Algorithms [29 Hours]

This course series explores Digital Signal Processing (DSP), an essential engineering field that has revolutionized interpersonal communication and on-demand entertainment over the past few decades. It combines principles of electronics, telecommunication, and computer science, enabling the creation of devices ranging from CDs and DVDs to mobile phones. The courses cover the basics of DSP, Fourier analysis, filter design, sampling, interpolation, and quantization, building a comprehensive DSP toolset to analyze a practical communication system. Practical examples bridge the gap between theory and practice. Proficiency in basic calculus and linear algebra and some programming knowledge are recommended for this course.

Sub-Topics

Digital Signal Processing: the Basics
Signal Processing Meets Vector Space
Fourier Analysis: the Basics
Fourier Analysis: More Advanced Tools

Formative Assessments:
4 graded quizzes.

Module 2: Digital Signal Processing 2: Filtering [18 Hours]

This course delves into Digital Signal Processing (DSP), a critical engineering field responsible for advancements in interpersonal communication and on-demand entertainment. It combines principles from electronics, telecommunication, and computer science, manifesting in devices like CDs, DVDs, MP3 players, and mobile phones. The course aims to equip students with core DSP principles, from discrete-time signals to Fourier analysis, filter design, sampling, and quantization. Practical demonstrations regularly bridge the gap between theoretical understanding and hands-on practice. Although basic proficiency in calculus and linear algebra is recommended, programming examples will be provided in Python, adaptable to any preferred programming language.

Sub-Topics
Digital Filters
Filter Design
Stochastic and Adaptive Signal Processing

Formative Assessments:
3 graded quizzes.

Module 3: Digital Signal Processing 3: Analog vs Digital [16 Hours]

This course, focused on Digital Signal Processing (DSP), explores the field that has reshaped electronics, telecommunication, and computer science principles, driving the digital revolution. It aims to teach students the fundamentals of DSP, from the basic definition of a discrete-time signal through to Fourier analysis, filter design, sampling, interpolation, and quantization, thus forming a comprehensive DSP toolkit. The course bridges the gap between theory and practice through regular hands-on examples and demonstrations. While basic proficiency in calculus and linear algebra is recommended, programming examples are provided in Python but can be adapted to any programming language.

Sub-Topics
Interpolation and Sampling
Aliasing
Multirate Signal Processing
A/D and D/A Conversion

Formative Assessments:
3 graded quizzes and 4 ungraded lab assignments.

Module 4: Digital Signal Processing 4: Applications [14 Hours]

This course aims to unravel Digital Signal Processing (DSP), the unique engineering field behind numerous digital advancements including CDs, DVDs, MP3 players, mobile phones, and other devices. Students will learn the fundamentals of DSP, starting with the basic definition of a discrete-time signal, through Fourier analysis, filter design, sampling, interpolation, and quantization. The course bridges theory and practice with regular hands-on examples and demonstrations. It's recommended for students to have proficiency in basic calculus and linear algebra, and though the course provides Python programming examples, the learners can choose their preferred programming language.

Sub-Topics
Digital Communications And Adsl
Image Processing
Real-Time Audio Signal Processing

Formative Assessments:
2 graded quizzes and 4 ungraded lab assignments.

Module 5: Semiconductor Physics [15 Hours]

This course, which can be taken for academic credit as part of CU Boulder's Master of Science in Electrical Engineering degree, provides a fundamental understanding of the quantum theory of solids and carrier behaviors in semiconductors. It successfully strikes a balance between the core physics concepts and their application in semiconductors and other electronic devices. By the end of the course, students will be able to comprehend energy band structures in solids, analysis of carrier statistics and dynamics in semiconductors, and their impact on conductive properties.

Sub-Topics
Carrier Dynamics
Carrier Statistics
Currents in Semiconductor
Quantum Theory Of Semiconductors

Formative Assessments:
4 graded quizzes and 3 peer-review assignments.

Module 6: Diode - pn Junction and Metal Semiconductor Contact [16 Hours]

This course provides an extensive exploration of pn junction and metal-semiconductor contacts. It includes analysis of equilibrium behavior, responses under bias, breakdown, non-rectifying behavior, and surface effect, with a focus on practical application to electronic devices. Upon completion of this course, students will have a firm grasp on analyzing equilibrium and biased conditions of pn junctions and metal-semiconductor contacts, their capacitance and current characteristics, breakdown behaviors, non-rectifying contacts, and surface effects.

Sub-Topics
Metal-Semiconductor Contact
Optoelectronic Devices
PN Junction at Equilibrium
PN Junction Under Bias

Formative Assessments:
4 graded quizzes.

Module 7: Transistor - Field Effect Transistor and Bipolar Junction Transistor [12 Hours]

This course provides detailed analysis and discussion of metal-oxide-semiconductor field effect transistors (MOSFETs) and bipolar junction transistors (BJTs). It focuses on understanding equilibrium characteristics, operation modes, switching, and current amplifying behaviors of these transistors. Upon course completion, learners would have the ability to understand and analyze MOS devices, MOSFETs, and BJTs.

Sub-Topics
Bipolar Junction Transistor (BJT)
Metal-Oxide-Semiconductor (MOS) Device
MOS Field Effect Transistor (MOSFET)

Formative Assessments:
3 graded quizzes and 1 peer-review assignment.

Module 8: High Voltage Schottky and p-n Diodes [19 Hours]

This course targets graduate students and professionals interested in power electronics and semiconductor devices. As the second course in the "Semiconductor Power Device" specialization, it offers a deeper understanding of high-voltage Schottky and p-n diodes, their physics, and the crystalline semiconductors fundamental to their analysis. It covers the calculation of carrier densities and currents leading to the drift-diffusion model. Additionally, the course focuses on the diodes' key figures, their SPICE models, and power losses in convertor circuits. By the end of the course, students will be equipped to understand high-voltage Schottky and p-n diodes in detail, calculate key diode parameters, and construct SPICE models for both types of diodes.

Sub-Topics
p-n Diodes
Power diode losses
Schottky diodes
Semiconductor physics background

Formative Assessments:
19 graded quizzes.

Module 9: Introduction to Power Semiconductor Switches [10 Hours]

This course primarily targets first-year graduate students and professionals interested in power electronics and semiconductor devices. It's the first course in the "Semiconductor Power Device" specialization, covering a gamut of devices from diodes, MOSFETs, IGBTs to state-of-the-art devices like silicon carbide (SiC) Schottky diodes and Gallium Nitride (GaN) HEMTs. The course offers an overview of these devices, their physics, circuit models, and fabrication technology. The initial focus is on semiconductor power switches, linking power converter applications with individual devices through detailed analysis and simulations.

Sub-Topics
Key Power Semiconductor Devices
Power Device Data Sheets
Power Device Losses in Switching Circuits
Power Semiconductor Device Basics

Formative Assessments:
12 graded quizzes.

Module 10: [Fundamentals of Semiconductor Characterization] [5 Hours]

The goal of this course is to review the fundamentals of semiconductor materials, p-n junction diodes, and MOS capacitors. There are many semiconductor technologies based on different material systems, but the most important is complementary metal-oxide-semiconductor, or CMOS for short. This course will focus on semiconductor materials and devices relevant to CMOS manufacturing, but the concepts can be applied much more broadly. Many of you may have already completed a semester-long class focused on devices, perhaps even more than one. However, if you took that class a while ago or have only the minimum exposure to semiconductor devices, we have developed this short course to review the fundamentals you will need to be successful in this specialization.

Sub-Topics
Semiconductor Basics
P-N Junction Diodes
MOS Capacitors

Formative Assessments:
2 graded quizzes.

Module 11: [Introduction to Semiconductor Packaging] [10 Hours]

This course will cover various aspects of microelectronics and nanoelectronics. This field aims to advance and improve the functionality of electronic devices by scaling transistors to smaller feature sizes. The course will introduce you to essential concepts such as length scales, transistor actions, and feature sizes of integrated circuits. The course will also look at historical observations and trends using Moore's Law, which currently guides and predicts development of the Semiconductor industry. Most importantly, our goal is to highlight why packaging is so important and relevant today. Furthermore, we will also explore the anatomy and function of a semiconductor package, starting with substrate-level package interconnection to the motherboard. We will also describe features as we differentiate various types of packages and how they differ in materials, design, and reliability.

Sub-Topics
Nanoelectronics
CHIPS+ and Semiconductor Packaging
Types of IC Packages:
Power diode losses
Anatomy of a Package
Semiconductor Package

Formative Assessments:

9 graded quizzes and 7 staff graded assignments.

Module 12: [Semiconductor Packaging Manufacturing] [9 Hours]

This course will provide information on the various stages of semiconductor package manufacturing, including sort, assembly, and final test. In addition, we will also describe how to select, build, and test the packages with the die and other components to ensure the quality of the package and total assembly performance. We will also discuss the role of Process Control Systems in semiconductor manufacturing as they relate to quality testing. Specifically, we will explore how Process Control Systems can help identify and correct process problems that cause variation and quality issues.

Finally, we also demonstrate how to use control charts to monitor the process performance. These can assist in decision-making, specifically when to take action to improve the process.

Sub-Topics
Semiconductor Package Manufacturing
BGA vs. LGA: The Difference between the Two Grid Arrays
Process Control Systems (PCS)
Die Bonding, Process for Placing a Chip on a Package Substrate
Keeping IC Packages Cool

Formative Assessments:
6 graded quizzes and 1 staff graded assignments.

Module 13: Advanced Semiconductor Packaging [6 Hours]

Throughout this course, you will be introduced to Pathway for Assembly and Packaging technologies for 7-nanometer silicon feature sizes and beyond. The course will present the evolution and impact of packaging on product performance and innovation. Specifically, we highlight how packaging has enabled better products via the use of heterogeneous integration by improving the interconnects for thermal management and signal integrity.

Sub-Topics
Packaging Trends
Challenges and recent prospectives of 3D heterogeneous integration
Future Challenges For Advanced Packaging
Evolution of IC Packaging
Advanced Packaging

Formative Assessments:
4 graded quizzes and 1 staff graded assignments.

Module 14: Electrical Characterization: Diodes [4 Hours]

The course begins with the definitions of resistivity and sheet resistance of semiconductors and metals and emphasizes the importance of working with the correct units for each. We see how to calculate the sheet resistance of a thin conducting film once we know its resistivity. A method to determine the contact resistance using the transfer length method is described, along with the definition of the specific contact resistivity. Current-voltage (IV) measurements of p-n junction diodes are used to extract key device parameters such as the ideality factor and series resistance. The course project explores how process monitor blocks are used to maintain manufacturing integrity.

Sub-Topics
Resistivity and Sheet Resistance
Resistance Measurements and Four-point Probes
Measuring Contact Resistance
The Current-voltage (IV) Characteristics of Diodes

Formative Assessments:
1 graded quiz.

Module 15: Electrical Characterization: MOSFETs [5 Hours]
MOSFET transistor switches are the workhorse of semiconductor-based electronics. In this course, we begin with MOS capacitors and see how to extract the oxide charge density, which is important for controlling the MOSFET threshold voltage. We then review MOSFET electrical characteristics and see how current-voltage measurements are used to determine the threshold voltage. The course project uses real-world data to extract the threshold voltage of a 40 nm gate length MOSFET designed for 5G radio frequency integrated circuits.

Sub-Topics
Extracting Oxide Charge Data From MOS C-V Measurements
MOSFET Characterization
MOSFET device parameters
Assess your ability to extract the threshold voltage of a MOSFET

Formative Assessments:
1 graded quizzes and 1 staff graded assignments.

Module 16: Electron and Ion Beam Characterization [5 Hours]

Electron and ion beams are widely used for both qualitative and quantitative analysis of semiconductor materials and devices. They can be used to image structures with sub-nm resolution and to provide information about elemental composition and dopant concentration. This course describes the fundamentals of electron and ion beam characterization and includes a project that analyzes the surface roughness of a solar cell.

Sub-Topics
Scanning Electron Microscopy
Auger Electron Spectroscopy
Secondary Ion Mass Spectroscopy
Course Wrap-up and Project

Formative Assessments:
1 graded quizzes and 1 staff graded assignments.

Module 17: Optical and X-Ray Characterization [4 Hours]

Optical and X-ray techniques are powerful ways to characterize semiconductor thin films. They can be used to measure film thickness, purity and crystalline quality, and for compositional analysis. Modern techniques are fast, turn-key, and generally non-destructive, allowing for rapid assessment of material properties. This course describes the fundamentals of optical and X-ray characterization and provides real-world examples of how they are used in semiconductor manufacturing.

Sub-Topics
Reflectance Spectroscopy
Ellipsometry
Photoluminescence
Electron Microprobe X-Ray Analysis
Course Wrap-up and Project

Formative Assessments:
1 graded quizzes.

ASSESSMENT:

For summative assessments, Coursera will provide question banks for which exams can be conducted on the Coursera platform or the faculty will create their own assessments.

Note: If a Course or Specialization becomes unavailable prior to the end of the Term, Coursera may replace such Course or Specialization with a reasonable alternative Course or Specialization.